

Comparing Short-term C Metabolism in Soils from Four Different Ecosystems

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Abstract

The rate at which a soil metabolizes new carbon may suggest its potential to sequester C. Soils from different ecosystems have different microorganisms and thus, may mineralize C differently. The soils were from four ecosystems: tallgrass prairie, cropland, shrub-steppe, and Douglas fir forest. We monitored transformation of a simple ¹⁴C-labeled substrate (glucose) over 12 weeks. Specific activities of evolved CO₂ were used to compare soils. The prairie soil showed no evidence of preferential metabolism of glucose-C, nor did it appear that endogenous C was particularly metabolized. Respiration patterns in the other three soils indicate that preferential metabolism did occur.

Introduction

The short-term cycling of C may offer insights to the C sequestration potential of a soil. Furthermore, the short-term cycling of carbon is intimately linked with the availability of nitrogen (Henriksen and Breland, 1999). Insufficient N may cause SOM degradation as SOM-N is “mined” by soil organisms, whereas an excess of N may cause SOM degradation as SOM-C is consumed in response. Sequestration of C in soils that are N-limited may be enhanced by the addition of an appropriate quantity of N, thereby preventing this microbial decomposition of native soil organic matter for N (Ladd et al., 1992).

The “priming” of endogenous soil C, *i.e.*, its mineralization in response to the addition of fresh C, can affect the long-term sequestration of C in soils (Bell et al., 2003). However, in some soils to which glucose was added, this priming effect has been observed to be offset by enhanced storage of the freshly added C in soil, resulting in a net increase in C storage in soil (Dalenberg and Jager, 1989). We propose that studying the short-term dynamics of freshly added carbon to soils will enhance our ability to speculate about the long-term fate of the freshly added C and its effect on the endogenous soil organic C. We compare the short-term mineralization of C from soils that were amended with a ¹⁴C-labeled readily available substrate (glucose) with those that were amended with glucose and nitrogen.

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Methods and Materials

The soils studied came from four ecosystems: the semiarid shrub-steppe (Richland, WA), a no-till wheat-pea farm (Palouse, WA), tallgrass prairie restored in 1979 (Batavia, IL), and a Douglas fir forest (Buckley, WA). Selected characteristics of these soils are presented in Table 1.

Subsamples (5 g) of surface soils (0-5 cm) collected from each ecosystem were treated with a quantity of ^{14}C -UL-glucose to generate maximum respiratory response (Table 2); no N was added (0). A second treatment was included in which N was added such that the ratio of added C:N was 20:1. Potassium hydroxide (0.5 M) traps were placed inside each incubation unit to capture respired CO_2 . Traps were changed weekly and titrated with HCl to determine CO_2 respiration for the 12 weeks of the experiment. The activity of these traps was also measured using liquid scintillation counting to determine the specific activity of the $^{14}\text{CO}_2$ evolved. Triplicate samples of each soil were destructively sampled at 1, 2, 4, 8, and 12 weeks. These soil samples were sequentially extracted for water soluble C (WSC), soil microbial biomass C (SMBC), and humic C (HC). Water extracts were done in a 1:10 soil:water slurry, SMBC determined by chloroform fumigation-extraction, and HC determined by overnight extraction of the non-fumigated half of the sample (0.5 M NaOH). Aliquots of each extract were counted to determine the activity of ^{14}C incorporated into each fraction.

Table 1. Selected characteristics of study soils, and the amount of C added as glucose to each soil in this experiment.

Location	Soil Texture	C (mg g ⁻¹ soil)	N (mg g ⁻¹ soil)	C addition (μg g ⁻¹ soil)
Shrub-steppe, Richland, WA	Loam	8.5	0.85	600
No-till farmland, Palouse, WA	Silt loam	46.6	36.7	1600
Restored tallgrass prairie, Batavia, IL (Fermi National Lab)	Silt loam	49.9	4.59	800
Douglas fir forest, Buckley, WA	Sandy loam	88.8	5.27	1600

Results and Discussion

The maximum utilization rate of glucose, indicated by $^{14}\text{CO}_2$ evolution, was not affected by N addition suggesting that none of the study soils were N-limited (Fig. 1). The pattern and metabolic use of the energy source differed among ecosystems.

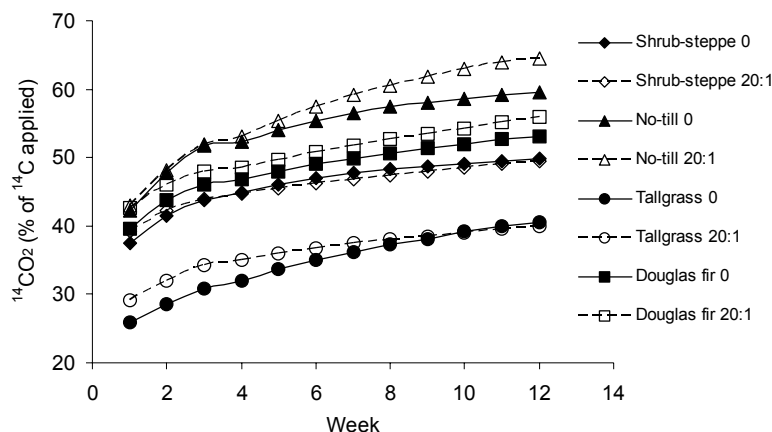


Figure 1. $^{14}\text{CO}_2$ evolution from soils treated with ^{14}C -UL-glucose alone, and from soils treated with ^{14}C -UL-glucose and nitrogen ($\text{C}_{\text{glucose}}:\text{N} = 20:1$).

Without the addition of N the no-till and Douglas fir soils showed a high metabolic throughput of added C possibly indicating a soil C limitation (Fig. 2). Whereas, the shrub-steppe and tallgrass soils showed a lower and steadier metabolism of glucose, indicating potentially more C storage from added substrates in these soils. With the addition of N the specific activity of CO_2 remained higher than the no N treatment such that the time to steady-state specific activity was increased by 1 to 2 weeks. This indicates induction of rapid recycling of C within microorganisms due to N addition.

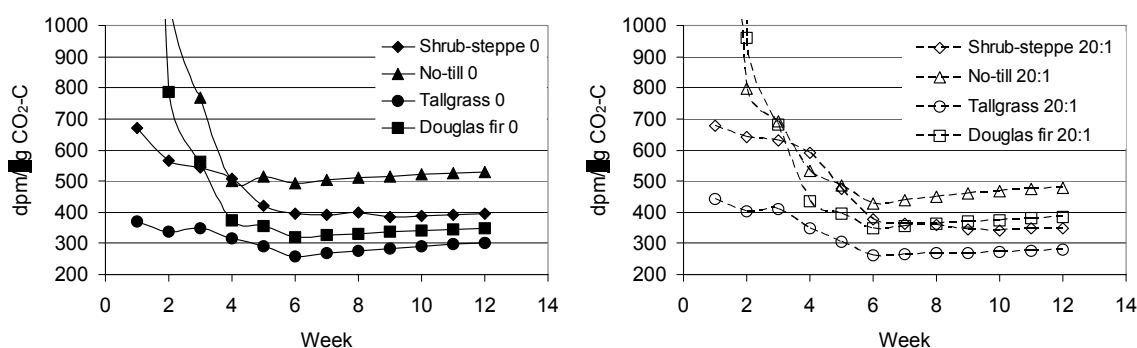


Figure 2. Specific activity of CO_2 evolved from (a) the four soils without additional N, and (b) the four soils with additional N.

Comparing the CO_2 specific activity of the 2 soils that showed potential for greater C storage (Fig. 3a) shows why we see little difference in total C utilization with N additions. The pattern of glucose consumption in the added N treatments is greater than without added N until week 6 where the specific activity decreases to below that of the no N addition soil. This decrease in the cycling of ^{14}C offsets the

initial rapid cycling and at 12 weeks the treatments are similar in substrate utilization. If these trends continued, more of the C added would be sequestered in the N treatment than the no N treatment suggesting that soils in which freshly added C is rapidly cycled will have the greatest C sequestering potential. However, in the soils with the high throughput of added C (Fig. 3b) the patterns were not so evident.

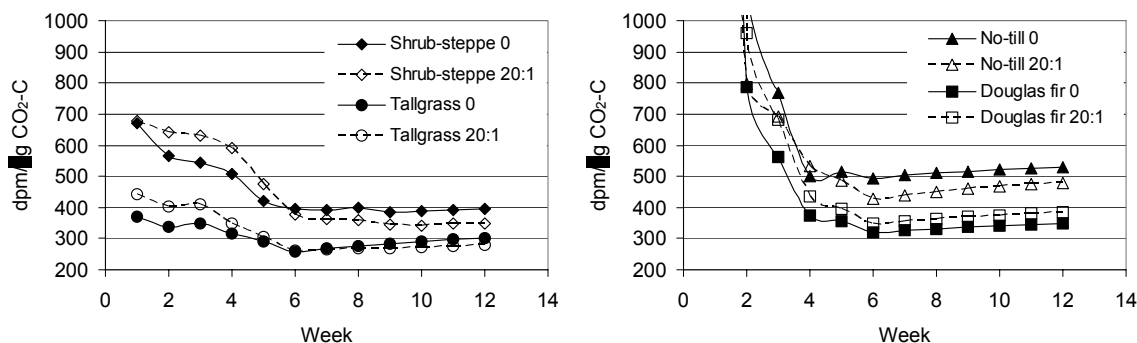


Figure 3. Specific activity of CO₂ evolved from (a) both treatments of the shrub-steppe and tallgrass prairie soils, and (b) both treatments of the no-till farmland and Douglas fir forest soils.

At the end of the incubation, the shrub-steppe soils had mineralized 50% of the ¹⁴C applied as glucose to ¹⁴CO₂ (Fig. 4). The no-till soil similarly mineralized 60-64% of the added ¹⁴C, the tallgrass prairie soil 40%, and the Douglas fir forest soil 53-56% (Fig. 4). The initial incorporation of the glucose-derived ¹⁴C into the humic fraction was rapid and tended to be greatest in the added N treatment. However over time this fraction was mineralized to CO₂. The remaining 40 to 60% of the added glucose cycled into a resistant soil C fraction after 12 weeks, however as seen in Figures 2 and 3 is still being mineralized at a slow rate. The rapid turnover of cellular material is evident by the small and consistent amount of ¹⁴C in the microbial biomass. It is noteworthy that 40-60% of the applied ¹⁴C was not recovered in any of the extracts. This suggests that it may be stored in the soils in a persistent form that is not readily available for microbial metabolism.

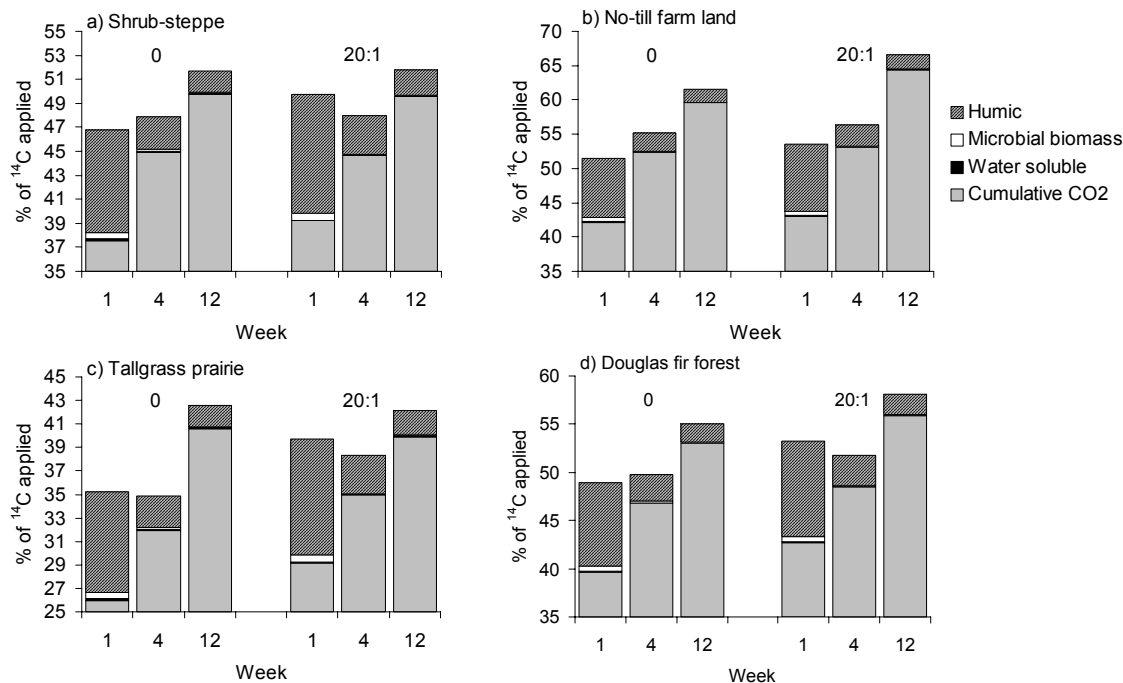


Figure 4. Redistribution of glucose-derived ^{14}C into humic-C, microbial biomass-C, water soluble-C, and CO_2 at 1, 4, and 12 weeks of incubation for both glucose (0) and glucose + N (20:1) treatments for all four soils: a) Shrub-steppe soil, b) No-till farmed soil, c) Tallgrass prairie soil, and d) Douglas fir forest soil.

Concluding Comments

Our study points out that using cumulative loss functions or cumulative production graphs do not show the internal dynamics of C cycling. In the utilization of glucose it appears that N had little effect, however on more detailed analysis we observed that over time N additions could force added C into more resistant soil C pools. This would result in greater C sequestration. In addition, it appears that the initial metabolic capacity of soils may indicate their potential for sequestering C. These types of substrate addition experiments may be useful in developing an index of soil C storage. Our follow up work will address the question of metabolic capacity versus potential C storage.

Acknowledgements

This research was supported by the Carbon Sequestration in Terrestrial Ecosystems (CSiTE) Program, Office of Biological and Environmental Research, U.S. Department of Energy. Pacific Northwest National Laboratory is operated for the DOE by Battelle Memorial Institute under contract DE-AC06-76RLO 1830. The authors are grateful for the assistance of SJ Fansler, HM Kostandarithes, AE Plymale, and K Zrotalova in conducting this research.

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